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FROST HEAVE MONITORING OF TEST FOOTINGS AT SELECTED TRANSFORMER STATIONS

Report No 87-253-K

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ABSTRACT

Several transformer stations across Ontario have reported heaving of light equipment foundations. To assess remedial designs, four types of test footings were installed and monitored at Port Hope TS, Ottawa Hawthorne TS and Pinard TS. Disturbed soil samples from each site were brought to the laboratory and tested for frost susceptibility. Results from the laboratory testing indicate that all the soils are frost susceptible to some degree and that soil heave could be reduced by increasing its compacted density. Results of the field monitoring indicate that the winter of 1986-87 was much warmer than normal leading to less frost penetration and ground heave. The most useful data, obtained from Pinard TS, indicate that the shaft/sleeve footing heaved less than others. It is recommended that the monitoring program be repeated for the winter of 1987-88 and that readings be taken on a bi-weekly basis from mid-October to late April.

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To Mr. J.H. Midgley
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FROST HEAVE MONITORING OF TEST FOOTINGS AT SELECTED TRANSFORMER STATIONS

1.0 INTRODUCTION

Many transformer stations across Ontario are located in frost susceptible soils with high water tables. Frost heaving of light equipment foundations and site drainage difficulties have occurred at a sufficient number of sites that a Task Group was commissioned to review these problems and recommend remedial designs. As part of this review process, trial remedial foundations were installed at three TS sites where foundation heave had been reported. This report documents the performance of these trial foundations during the winter of 1986-87 and results of laboratory tests on the soils from these sites.

1.1 Testing Program

The field study involved installing four types of test footings (shaft/sleeve, augered, insulated and screw-in) at three transformer stations, two in south of the Province and one in the north. In addition, several sets of frost depth and frost heave gauges were installed in the vicinity of the footings to monitor ground response to freezing temperatures. Gauge readings and surveys were made on a monthly basis to provide field data for analysis.

The laboratory portion of the study was conducted on disturbed soil samples obtained from the installation of the test footings. Frost susceptibility was assessed by two methods: 1) grain size distribution and 2) small scale frost heave testing.

1.2 Test Sites

Three test sites were chosen to study the frost heave problem: 1) Pinard TS, located 150 km north of Timmins, has required extensive rehabilitation of HP air piping due to frost heaving; 2) Ottawa-Hawthorne TS, located in the southeast end of Ottawa, has experienced frost heave problems which must be resolved before addition of a 500 kV switchyard; 3) Port Hope TS, located east of the City of Port Hope, has reported frost heaving of some foundations. The installation of test footings and instrumentation was completed on November 19, 1986 at Pinard TS, December 2 at Ottawa-Hawthorne TS and December 1 at Port Hope TS.

2.0 LABORATORY STUDY

2.1 Grain Size Analyses

The grain size distribution curves for soils from Port Hope, Ottawa-Hawthorne and Pinard transformer stations are presented in Figures 1 to 4. The frost susceptibility envelope displayed on these graphs originates from experimental investigations by the British Road Research Laboratory (1952) in southern England.

The Port Hope samples are classified as silty sand tills with 84% of the grain size distribution within the frost susceptible limits. The Ottawa-Hawthorne samples are classified as silty fine sands with 65% of the distribution being frost susceptible. The Pinard samples are classified as sandy silt tills with generally 90% of the distribution within the frost susceptible limits. The Pinard soil sample from Footing #2 contains less silt and more gravel-sized particles and may be somewhat less frost susceptible.

Casagrande's frost susceptibility classification states that uniform soils ($D60/D10 < 5$) and well-graded soils ($D60/D10 > 5$) are frost susceptible if more than 10% and 3% of their sizes are less than 0.02 mm respectively. The parameters D60 and D10 correspond to the particle sizes at 60% and 10% passing. Based on this criterion, all of the soils tested are frost susceptible.

These textural and grain-size distribution criteria have limited predictive capabilities since they do not take into account the important in situ parameters of density and moisture content. These parameters control the size and distribution of soil pores, which in turn control the amount and rate at which water can be supplied to the freezing point.

2.2 Laboratory Frost Heave Tests

A laboratory frost heave test, using the Soil Sciences Section "frost box", was conducted on several soil samples from Port Hope, Ottawa-Hawthorne and Pinard transformer stations. For this test, individual soil specimens are placed into acrylic cylinders 20.3 cm long and 10.5 cm in diameter with perforated acrylic baseplates fitted to the bottom of each container. Changes

in height of the specimens are measured by means of a dial gauge mounted on a bar which rests on top of the cylinder.

The "frost box", shown in Figures 5 and 6, is constructed of plywood and lined with a 2.5 cm thick sheet of polyurethane foam. A steel pan, located in the bottom of the box, contains water to simulate the ground water table. A total of eleven acrylic cylinders are placed on top of a wire grate within the "frost box" so that the bottom of the samples are about 2.5 cm below the water surface. Three additional layers of polyurethane foam, with eleven holes cut out, are placed on top of the pan to complete the insulation of the water reservoir.

The frost box assembly is placed in a suitable freezer which maintains a freezing temperature of approximately -17°C. The water within the frost box is maintained at a temperature of approximately + 4°C by an array of heating cables connected to an external heat regulator. Water and air temperatures are monitored by thermocouples placed at various points within the frost box assembly. Thermocouples and dial gauge readings are taken periodically throughout the testing program which has a duration of approximately 240 hours.

2.2.1 Sample Preparation

The objective of the frost box testing was to determine the amount of heave exhibited by each soil type when compacted to near the field density. The following immersion densities were determined from bulk samples: 2214 and 2211 kg/m^3 for Pinard and 2066 kg/m^3 for Ottawa-Hawthorne. An immersion density for Port Hope could not be obtained because of the extent of disturbance to the samples.

Eleven samples from the three transformer stations were compacted in Proctor molds (10 cm diameter). When not compacted to field densities, samples were compacted using the standard Proctor method of 3 layers at 25 blows of a 5.5 lb hammer per layer, producing a compactive energy per volume of 12,400 ft/lb cu ft. When samples with similar grain size distributions were tested, one of these was under compacted at 20 blows per layer to observe the effect of lower densities upon frost heave. Following extrusion, the outside of the specimens were coated with petroleum jelly and placed into the acrylic cylinders. The annular space between the specimen and cylinder was sealed with petroleum jelly to prevent freezing.

2.2.2 Frost Box Test Results

Air and water temperatures recorded throughout the test are averaged and plotted in Figure 7. Freezer air temperatures ranged between -7 and -9°C and water temperatures ranged between 4 and 5°C. This corresponds to an induced thermal gradient of 0.09°C/mm to 0.1°C/mm. The amount of heave with time for Port Hope, Ottawa-Hawthorne and Pinard specimens are plotted in Figures 8 to 10. The total heave for each specimen is provided in Table I. Pictures of

the specimens extruded from the test cylinders are shown in Figures 11 to 13.

Fluctuations in the heave rates of every specimen are a direct result of changes in temperature as plotted in Figure 7.

Specimens compacted to a field density heaved less than all others. This result implies that disturbance of soil around poured in place footings, or less than perfect compaction of backfilled natural soil, may increase heave of small footings.

In general, specimens showed increasing amounts of heave in the following order: Port Hope, Pinard and Ottawa-Hawthorne. The frost susceptibility classification developed by the Transport and Road Research Laboratory (TRRL) in England, can be applied to the results of the Civil Research frost box test even though the imposed thermal gradient in the former is 0.14°C/mm. Readings below 12.7 mm are considered satisfactory and readings above 17.8 mm are considered unsatisfactory. These ratings should be taken at 250 hours for uniformity. Based on the TRRL classification, the Port Hope specimens are satisfactory, the Pinard specimens at field density are satisfactory to marginal, and all of the Ottawa-Hawthorne specimens are unsatisfactory.

3.0 FIELD STUDY

3.1 Instrumentation

3.1.1 Frost Heave Gauge

This instrument, shown in Figure 14, consists of a 1/2 inch (1.3 cm) diameter, grease-filled pipe casing, 5 ft (1.5 m) long with a 1 foot (30.5 cm) square plate welded to it. The casing is placed into the ground in tight contact with the soil and with the square plate about 6 inches (15.3 cm) below ground surface. At least 1 foot (30.5 cm) of casing is left above ground and the soil above the plate is well compacted. A 1/4 inch (0.6 cm) diameter steel rod is pushed down the greased casing and driven into the ground below the expected frost depth. A sight gauge is attached to the top of the casing with the rod inside. As ground heave lifts the casing and sight gauge, reading the position of the top of the anchored rod provides the magnitude of movement.

3.1.2 Frost Depth Gauge

This gauge, shown in Figure 15, consists of a 1/2 inch (1.3 cm) diameter tube made of polycarbon rigid plastic with a 3/8 inch (1 cm) diameter, gum rubber tube held stretched on the inside by two 3/8 inch tube test plugs. The space between the inner rubber tube and the polycarbon tube is filled with methylene blue dyed water. The complete gauge is inserted into the ground inside a 1/2 inch diameter PVC casing placed tightly in the soil. The length of all the segments is governed by the depth of monitoring. As the soil freezes to a certain depth, the fluid inside the polycarbon tube also freezes turning white

in colour, the gauge is periodically withdrawn from the casing and the depth of frost measured.

3.1.3 Thermocouple Depth Gauge

This device consists of a series of thermocouples anchored at appropriate intervals along a 1/2 inch (1.3 cm) diameter PVC rod. The thermocouple wire is usually of the copper constantine type. In this study, the thermocouple tree was used to monitor the effectiveness of insulation placed around an augered footing. Thermocouples were located 1 ft above ground, at ground surface and at 2 ft intervals along the length of the insulated footing (Figure 16). The thermocouple leads were placed below the insulation with the ends located within a protective housing at surface. Some thermocouples were also placed underneath the insulation, away from the footing. Periodic temperature readings were made by connecting the thermocouple ends to an appropriate meter.

3.1.4 Footings

Four types of footings were installed at each site: shaft/sleeve, augered, insulated and Chance streetlight. Diagrams of each footing are shown in Figure 17. All concrete footings were 24 inches in diameter and only nominal reinforcement was used. Deeper footings were used at Pinard TS because of the greater potential for frost heave.

The elevations of the top of all footings were surveyed shortly after installation and then periodically throughout the winter months. Transformer foundations were assumed immobile and used as benchmarks for the surveys.

3.2 Instrumentation and Footing Layout

Figure 18 shows the layout of the frost heave instrumentation and footings at all three sites. In general, three sets of frost heave and depth gauges were placed in the soil between the four test footings and one set placed a short distance away. At Ottawa-Hawthorne TS and Pinard TS, this fourth set was located next to older footings that had heaved severely in the past.

3.3 Field Monitoring Results

The monitoring data gathered over the winter of 1986-87 for Port Hope TS, Ottawa-Hawthorne TS and Pinard TS are presented in Tables II, III and IV respectively. The results are tabulated as changes in footing elevation, changes in frost heave gauge position, absolute frost depths and thermocouple readings where applicable.

Air temperature data are also available from four Environment Canada weather stations at Port Hope, Ottawa CDA, Island Falls and Smoky Falls. Island Falls and Smoky Falls are weather monitoring stations southeast and northwest respectively of Pinard TS. The temperature data are plotted as mean monthly

temperatures from December to April for 1983 to 1987 including a normal monthly temperature based on values for the 1951-80 period (Figures 19 to 22).

3.3.1 Port Hope TS

Mean monthly temperatures from December to April 1987 were all approximately 2° higher than normal except for February which had a normal monthly temperature of -5.2°C.

The maximum recorded frost depths occurred at the beginning of March and ranged from 23 to 39 cm between the test footings, to 61 cm further away. These values are much less than the maximum frost depth of 100 cm based on a freezing index of 500 degree-days and Brown's 1964 relationship for bare surfaces free of vegetation and snow cover.

The maximum recorded heave of the frost gauges was 1.6 cm at gauge A and 2.1 cm at gauge D. Some settlement of the frost heave gauges at B and C occurred after installation and readings remained negative throughout the recording period. A residual heave of 0.9 cm remained at gauges A and D even though frost was no longer in the ground on April 22.

A maximum heave of 0.6 cm was recorded for all test footings on February 5 which reduced to 0.3 cm on March 6. The similarity in all of these readings and the fact that maximum heave of the footings did not coincide with maximum heave of the frost gauges, casts some doubt on the validity of these measurements.

Thermocouple readings along the insulated footing indicate that below zero temperatures were not attained and that an increasing temperature gradient with depth persisted until April. Temperatures recorded directly underneath the insulation (#1, 11 and 12) were very consistent and reached a minimum of 1.5 C on March 6, 1987.

3.3.2 Ottawa-Hawthorne TS

Mean monthly temperatures plotted on Figure 20 indicate that the winter of 1987 was between 2 and 3°C warmer than normal, except for February which had a normal monthly temperature of -9.5°C.

Frost depths were only recorded on March 13 and ranged between 27 and 48 cm. These values are substantially smaller than the maximum frost penetration of 180 cm based on an average freezing index of 1000 degree-days and the relationship developed by Brown (1964) for exposed ground surfaces.

No heave was recorded at any of the frost heave gauges. This lack of movement coupled with low frost penetrations was caused by 1) higher average air temperatures, and 2) excess snow cover on the test footings from clearing of an adjacent access road.

The maximum recorded footing heave was 2.9 cm for Footing #2 (augered footing) on April 3. Since there was no frost depth recorded on that day, the footing was probably settling to some residual value which was recorded on April 27. The greatest recorded heaves of 2.9 and 2.6 cm were associated with the augered footing and insulated footing respectively. The shaft/sleeve and Chance footings showed only settlement and slight heave. The lack of coincident heave of the frost gauges and a maximum frost penetration of only 48 cm, may indicate that the footing surveys are inaccurate.

No thermocouple readings were available for Ottawa-Hawthorne TS.

3.3.3 Pinard TS

Mean monthly temperatures for Smoky Falls and Island Falls are plotted on Figures 21 and 22 respectively. The 1987 temperatures are between 2.5 and 6.7° C warmer than normal throughout the December to April period. The lowest monthly temperatures recorded in February of 1987 were -13.8°C and -15.2°C for Smoky Falls and Island Falls respectively. This contrasts with a normal low of -19°C during the month of January.

The frost gauges were installed on November 19, 1986 and the initial test footing survey was made on November 24. Significant frost depths recorded on November 24 indicate that frost had already penetrated into the ground before the test footings were installed. Throughout the monitoring period, frost penetration depths between the test footings ranged from 23 to 55 cm. Frost gauge D, located next to an HP air pipe recorded the deepest penetrations, ranging from 51 cm in December to 89.5 cm in mid-March, 1987. These frost depths are much less than the maximum penetration of 250 cm based on a freezing index of 1800 degree-days and no snow cover.

The maximum recorded heave of the frost gauges was approximately 4 cm on March 17, 1987. Frost heave gauge B, located between the shaft/sleeve and augered footings, showed consistently less movement reaching a maximum of 1.1 cm in mid-March. This behaviour does not coincide with less frost penetration, as given by frost depth gauge B, but does coincide with the coarser grained soil from Footing #2.

The maximum recorded heave of the test footings was on February 18, 1987, ranging from 4.8 cm for the augered footing, to 5.8 cm for the insulated footing. In general, the insulated footing and the Chance screw-in footing heaved more than the augered and shaft/sleeve footings. Settlement of the Chance footing was recorded in mid-March, even though frost was still in the ground and the average monthly temperature was -6°C. Insufficient readings were taken to determine the degree of residual displacement following the spring thaw.

Temperature readings from Footing #1 indicate that the insulation around the footing helped to keep ground temperatures above freezing. However, because of the inaccuracy of thermocouples, recorded temperatures within 1°C of freezing may be considered to be at the freezing point. This would mean that

ground freezing had occurred at a depth of 60 cm in mid-March 1987, and that the 10 cm thick insulation was not sufficient for Pinard TS.

4.0 CONCLUSIONS

The winter of 1987 was characterized by temperatures substantially above normal. Based on readings provided by the Meteorological Section of the Resource Utilization Department, winter in southern Ontario was 2 to 3°C above normal for all months except February, and in northern Ontario temperatures were 2.5 to 7°C above normal throughout the winter period. Field test results obtained during 1987 do not reflect the normal heaving behaviour of soils and small footings because of the warmer temperatures.

The frost susceptibility classification based upon the grain size distribution envelope of Figures 1 to 4 is not entirely satisfactory when compared to the results of the frost box test. The large heaves of the well graded Ottawa-Hawthorne soils could not have been predicted based on Figure 2. Although the Port Hope and Pinard soils appeared equally frost susceptible, the smaller percentage of silt and fine sand in the Port Hope specimens resulted in less total heave in the frost box. Based upon the results of the frost box test, the following specimens are ranked in order of increasing frost susceptibility: Port Hope, Pinard, Ottawa-Hawthorne.

The results of the field program were difficult to interpret and were somewhat inconclusive because of the following reasons: 1) winter temperatures were much higher than usual, leading to small or no heave; 2) the smaller movements tended to accentuate inaccuracies in the instrumentation and surveying; 3) variable amounts of snow cover at each test site influenced the depths of frost penetration and consequent heaving; 4) significant correlations between frost depth, ground heave and footing heave could not be made because of insufficient readings; 5) average monthly temperatures when the installations were completed, were already below freezing, especially at Pinard TS.

Based upon the available data, the following conclusions can be drawn for test footing performance:

- The 10 cm-thick insulation used at Port Hope TS helped to maintain ground temperatures around the footing at above freezing. The same thickness of insulation used at Pinard TS did not prevent freezing temperatures from migrating at least 60 cm below ground surface.
- Of the four types of test footings at Ottawa-Hawthorne and Pinard TS, the shaft/sleeve type consistently heaved less than the others. The behaviour of the Chance footing was too inconsistent, therefore an evaluation of its performance cannot be made at this time.
- Residual heave is an important factor in footing selection, therefore surveying should continue well into the spring time.

5.0 RECOMMENDATIONS

The field monitoring program should be repeated in 1988 to allow a better assessment of test footing performance. The following changes in the program are recommended to increase the usefulness of collected data:

- Instrumentation readings and surveying should begin well in advance of freezing temperatures and continue on bi-weekly basis until late spring. This requires a monitoring period from mid-October to late April at Pinard TS and from November to late March at Ottawa-Hawthorne and Port Hope.

- Along with the bi-weekly readings, a measurement of snow cover at the test sites should be made to help evaluate the frost penetration depths. Only natural snow fall should be allowed to accumulate around the test footings and instrumentation.

- An extra 5 cm of insulation should be placed around the insulated footing at Pinard TS to prevent the advance of freezing temperatures into the surrounding soil.

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1. Brown, W.G. "Difficulties Associated with Predicting Depth of Freeze or Thaw". Can Geotechnical Journal, Vol 1, No 4, Nov, 1964, p 215-226.

2. British Road Research Laboratory "Soil Mechanics for Road Engineers". 1952, p 343.

TABLE I

Results of Frost Box Test with an Induced Thermal Gradient of 0.09 to 0.1°C/mm

	Total Heave at 240 Hours (mm)	
PORT HOPE #1	6	
#2	3	
#3	3	
OTTAWA-HAWTHORNE #1	35	(2066 kg/m^3)
#1A	50	
#2	40	
PINARD #1	8	(2214 kg/m^3)
#2	42	
#3	16	
#4	30	

TABLE II

PORT HOPE TS

Elevation Change of Footings (cm) relative to Dec 1/86 readings

Footing #	Dec 1/86	Feb 5/87	March 6/87	April 22/87
1	-	0.6	0.3	0.3
2	-	0.6	0.3	0.3
3	-	0.6	0.3	0.3
4	-	0.6	0.3	0.3

Movement of Frost Heave Gauges (cm) relative to Dec 1/86 readings

Gauge #	Dec 1/86	Feb 5/87	March 6/87	April 22/87
A	-	-0.5	1.6	0.9
B	-	-	-0.2	-0.2
C	-	-0.5	-0.8	-0.8
D	-	0.8	2.1	0.9

NOTE: Positive Changes Indicate Heave

Frost Depth Gauges (cm)

Gauge #	Dec 1/86	Feb 5/87	March 6/87	April 22/87
A	0	19.7	39.4	0
B	0	0	24.1	0
C	0	10.8	22.9	0
D	0	29.8	60.9	0

Thermocouple Readings (°C)

Thermocouple #	Feb 5/87	March 6/87	April 22/87
1 (30.5 cm BGL)	2.8	1.5	10.9
2 (61 cm BGL)	4.2	2.3	8.6
3 (91.5 cm BGL)	4.7	2.6	7.0
4 (122 cm BGL)	5.2	3.3	6.0
10 (air)	-	8.6	12.5
11 (61 cm*)	3.4	1.6	9.8
12 (122 cm*)	3.0	1.7	9.0

NOTE: BGL = below ground level
* = under insulation and away from footing

TABLE III

OTTAWA-HAWTHORNE TS

Elevation Change of Footings (cm) relative to Dec 11/86 readings

Footing #	Dec 11/86	March 13/87	April 3/87	April 27/87
1	-	-0.2	0.2	-0.3
2	-	2.2	2.9	2.2
3	-	2.3	2.6	1.9
4	-	0.1	0.5	1.7
1A (old footing)	-	-0.2	0.1	-0.2

Frost Depth (cm)

Gauge #	Dec 11/86	March 13/87	April 3/87	April 27/87
A	0	26.7	0	0
B	0	33.0	0	0
C	0	48.3	0	0
D	0	-	0	0

NOTE: - no heave recorded on frost heave gauges
- gauge #4 broken shortly after installation

TABLE IV

PINARD TS

Elevation Change of Footings (cm) relative to Nov 24/86 reading

Footing #	Dec 17/86	Feb 18/87	March 17/87
1	1.0	5.8	1.3
2	0.5	5.1	1.0
3	0.5	4.8	1.3
4	1.0	5.6	-2.3

Frost Heave Gauge Readings (cm) relative to Nov 19/86 readings

Gauge #	Nov 24/86	Dec 18/86	Jan 29/87	March 17/87
A	0.6	0.6	1.9	3.9
B	0.2	-0.2	0.5	1.1
C	0	0.6	1.3	3.8
D	0.6	0.6	1.3	3.8

NOTE: Positive readings indicate heave

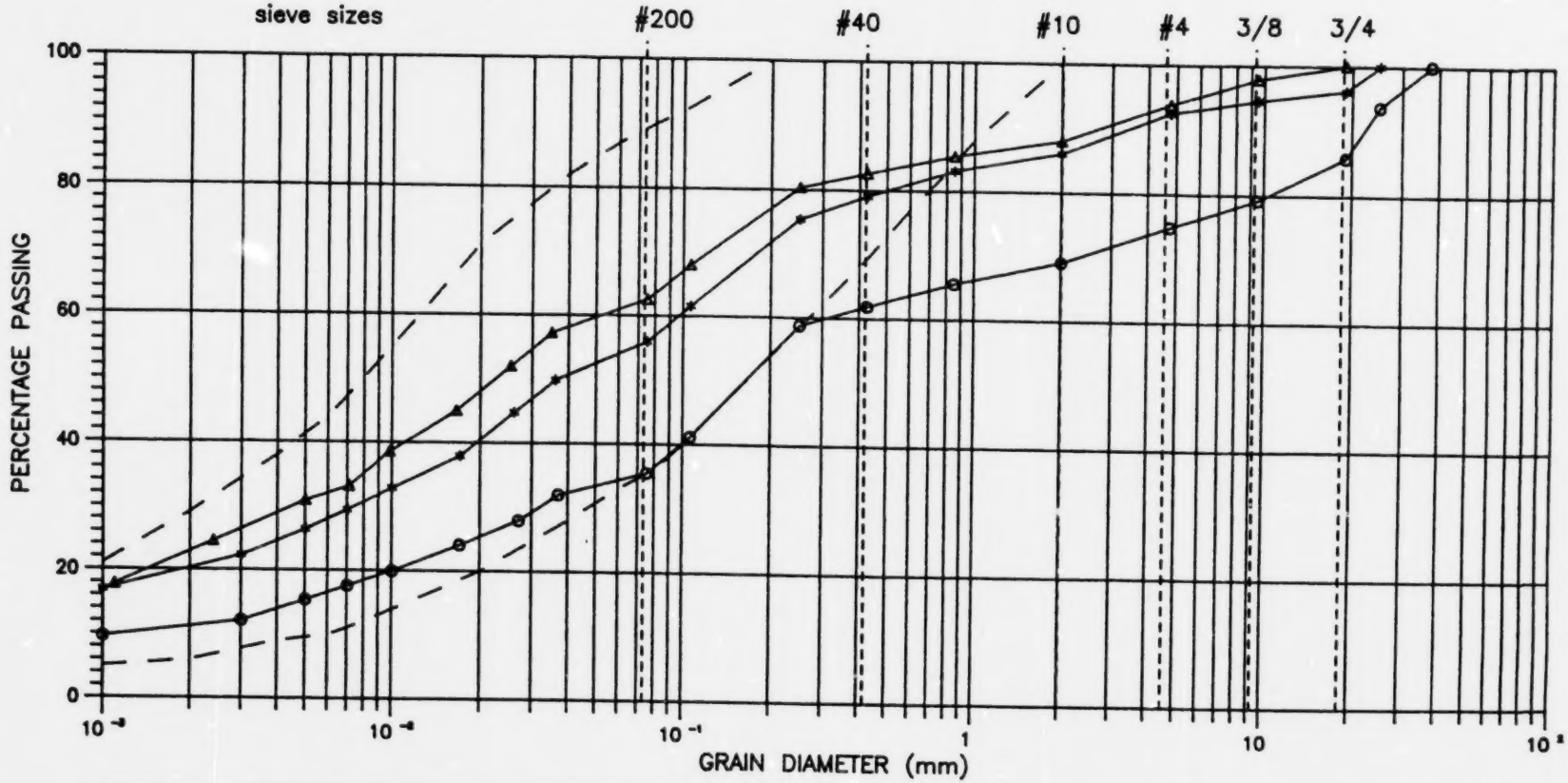
Frost Depth Gauges (cm)

Gauge #	Nov 24/86	Dec 18/86	Jan 29/87	March 17/87
A	45.1	48.3	45.7	-
B	39.4	31.8	45.7	44.4
C	29.2	22.9	30.5	55.2
D	66.0	50.8	50.8	89.5

Thermocouple Readings (C)

Thermocouple #	Jan 29/87	Feb 18/87	March 17/87
1 (183 cm BGL)	8.4	5.3	4.1
2 (122 cm BGL)	6.9	4.1	3.3
3 (61 cm BGL)	4.6	2.1	0.9
4 (0 cm BGL)	3.2	1.3	1.6
5 (30 cm AGL)	7.8	3.9	19.9

NOTE: BGL = below ground level
AGL = above ground level



△ – footing #1 : o – footing #2 : * – footing #3

PARTICLE SIZE LIMITS WITHIN WHICH SOILS ARE LIKELY TO BE FROST SUSCEPTIBLE

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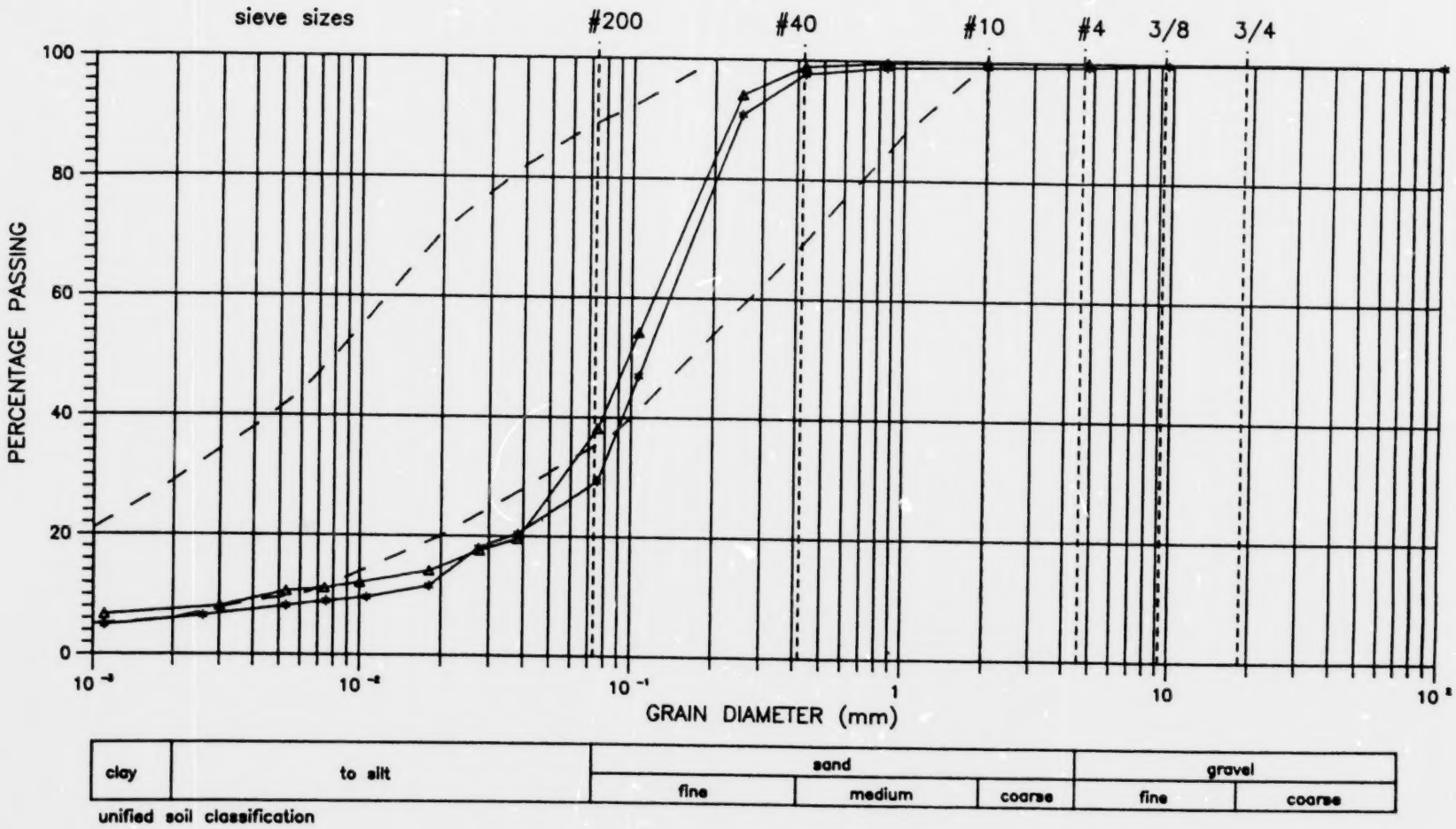
FIGURE 1

MECHANICAL ANALYSIS - PORT HOPE TS

87-253-K-75711-RD



PARTICLE SIZE LIMITS WITHIN WHICH SOILS ARE LIKELY TO BE FROST SUSCEPTIBLE

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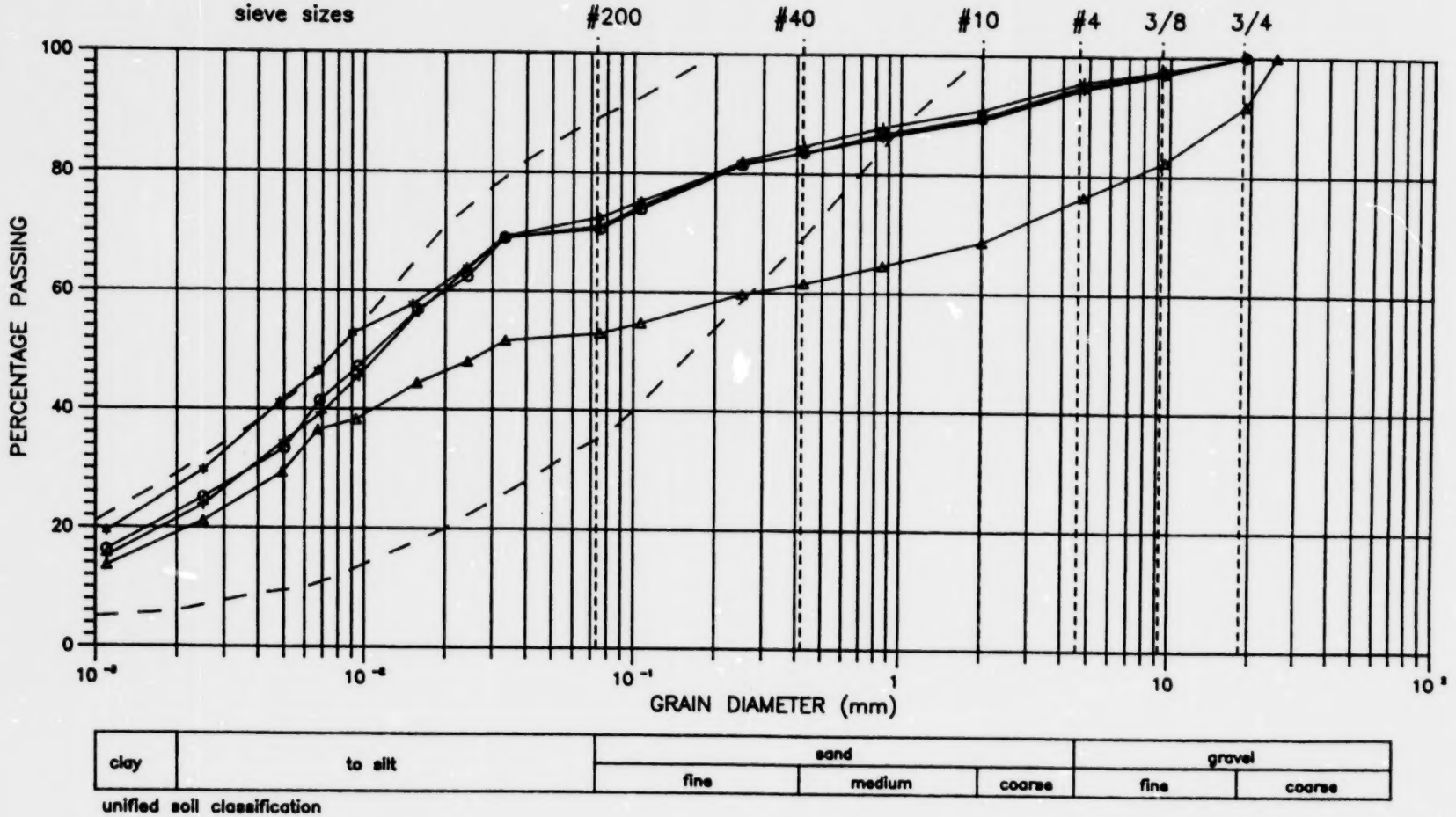
FIGURE 2

MECHANICAL ANALYSIS - OTTAWA HAWTHORNE TS



* – footing #1 : Δ – footing #2 : o – footing #3 : + – footing #4

PARTICLE SIZE LIMITS WITHIN WHICH SOILS ARE LIKELY TO BE FROST SUSCEPTIBLE

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FIGURE 3

MECHANICAL ANALYSIS - PINARD TS

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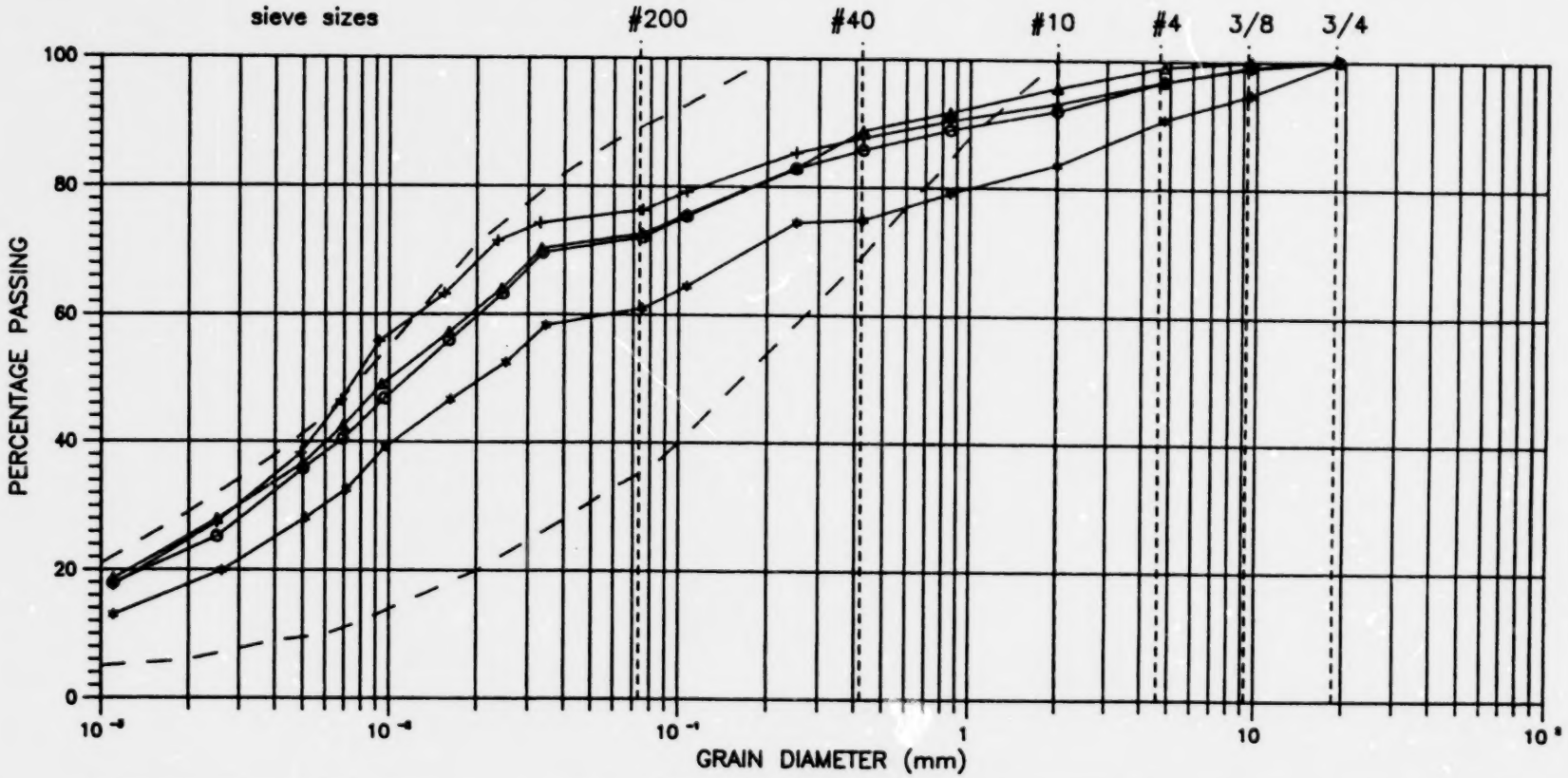

PARTICLE SIZE LIMITS WITHIN WHICH SOILS ARE LIKELY TO BE FROST SUSCEPTIBLE

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FIGURE 4

MECHANICAL ANALYSIS - PINARD TS

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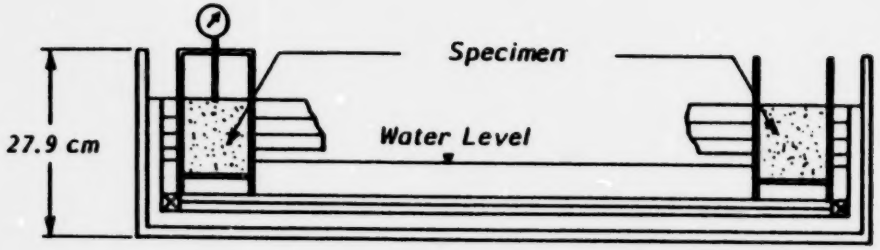
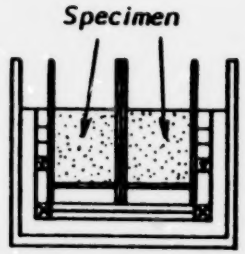
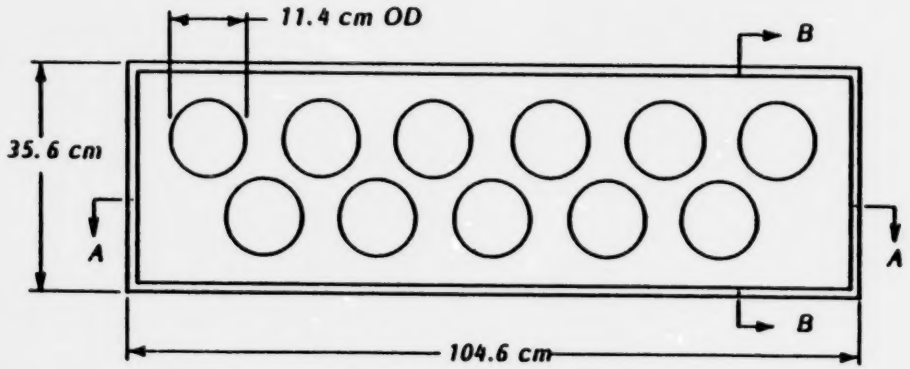
t25714-RD



Section A-A



Section B-B



Plan

Scale 1 = 10

FIGURE 5
FROST BOX DETAILS

162887 RD
87-253

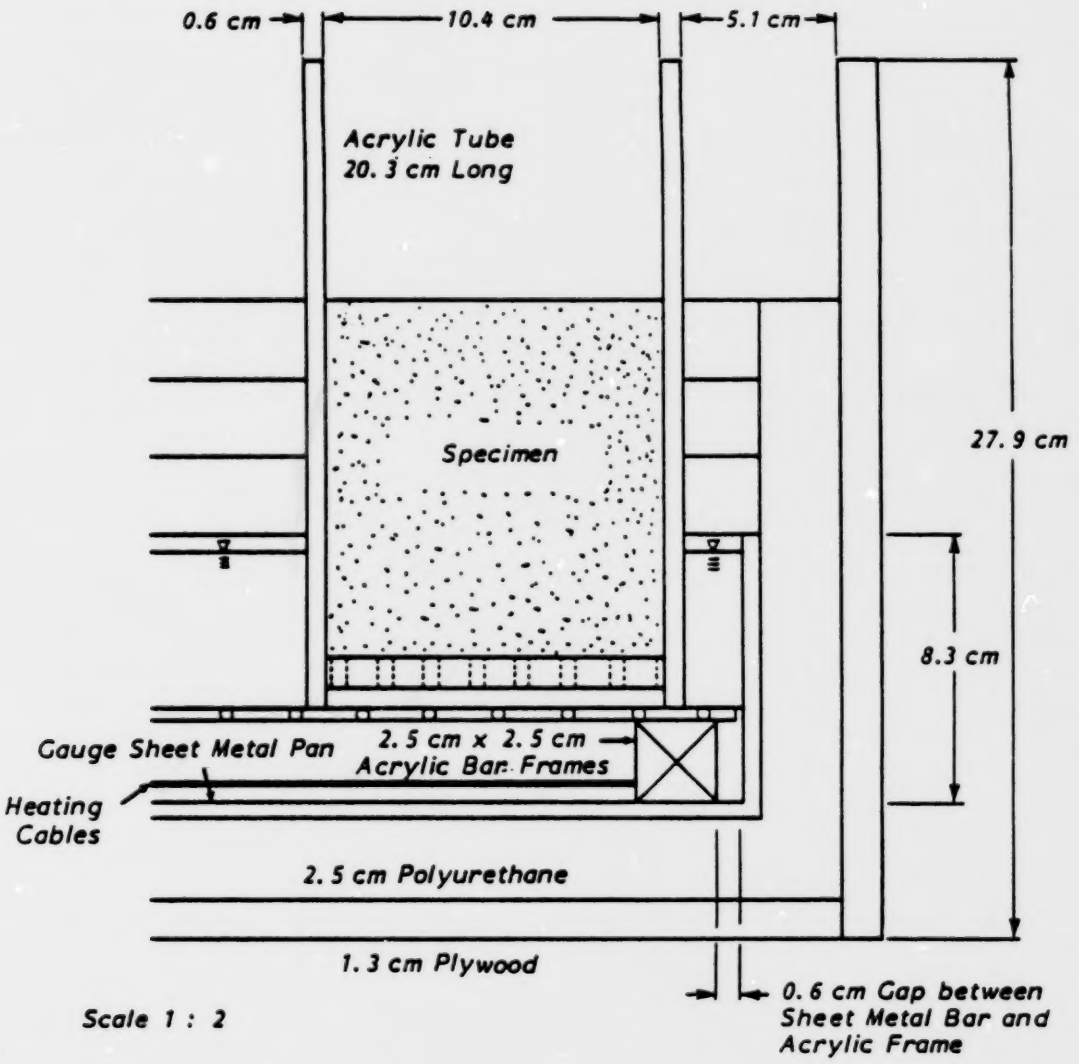


FIGURE 6
FROST BOX DETAILS

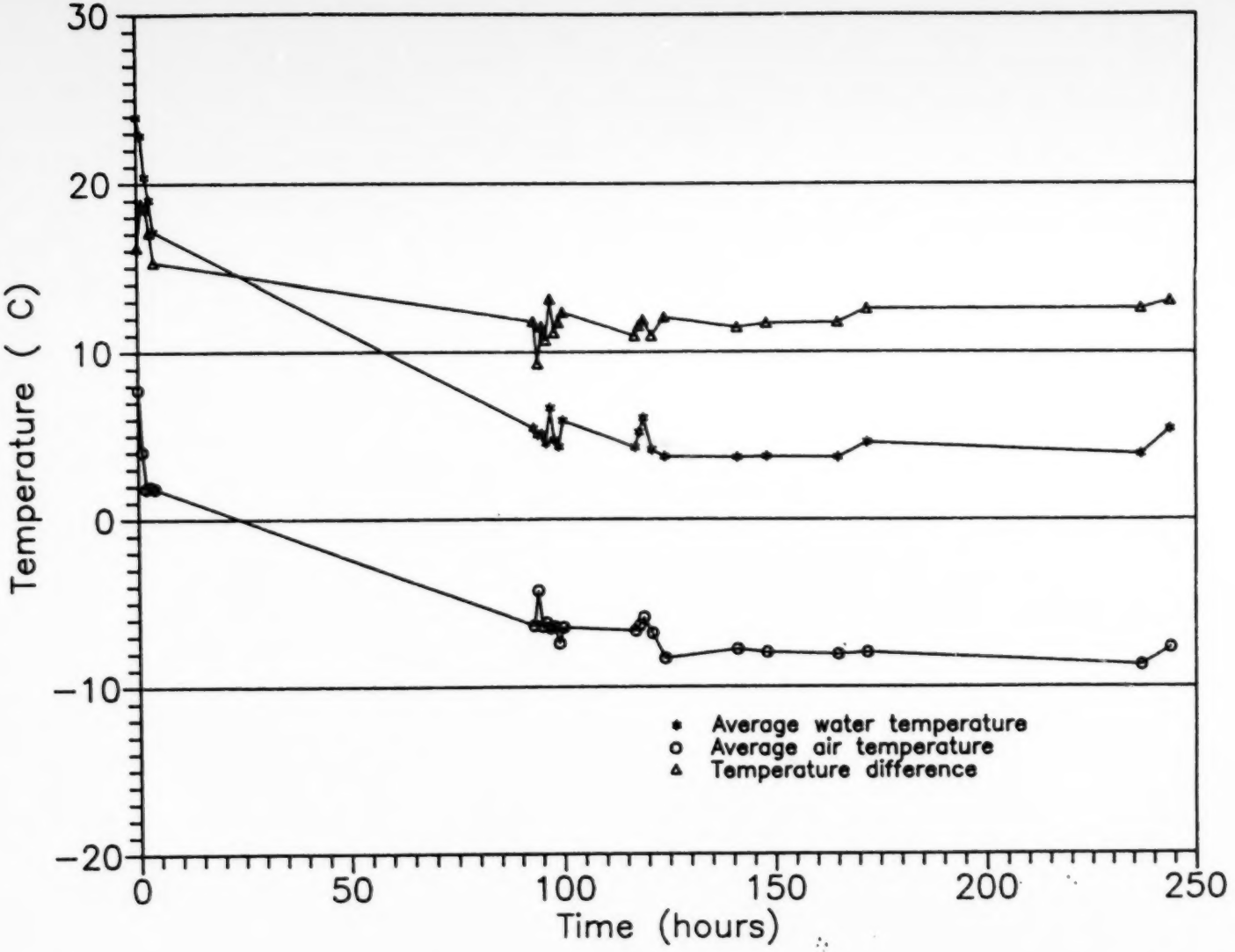


FIGURE 7

FROST BOX TEST RESULTS - THERMOCOUPLE READINGS

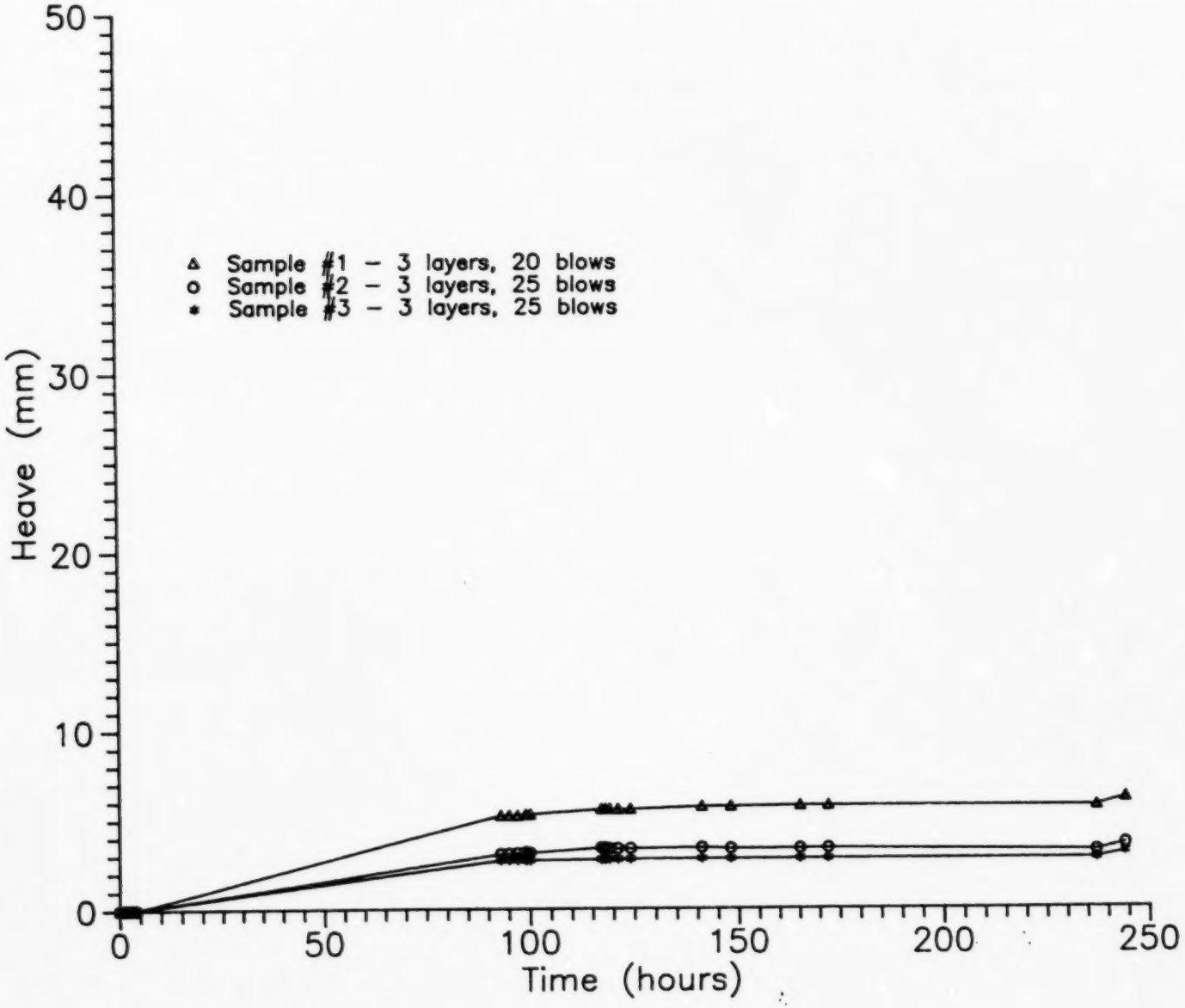


FIGURE 8
FROST BOX TEST RESULTS - PORT HOPE TS

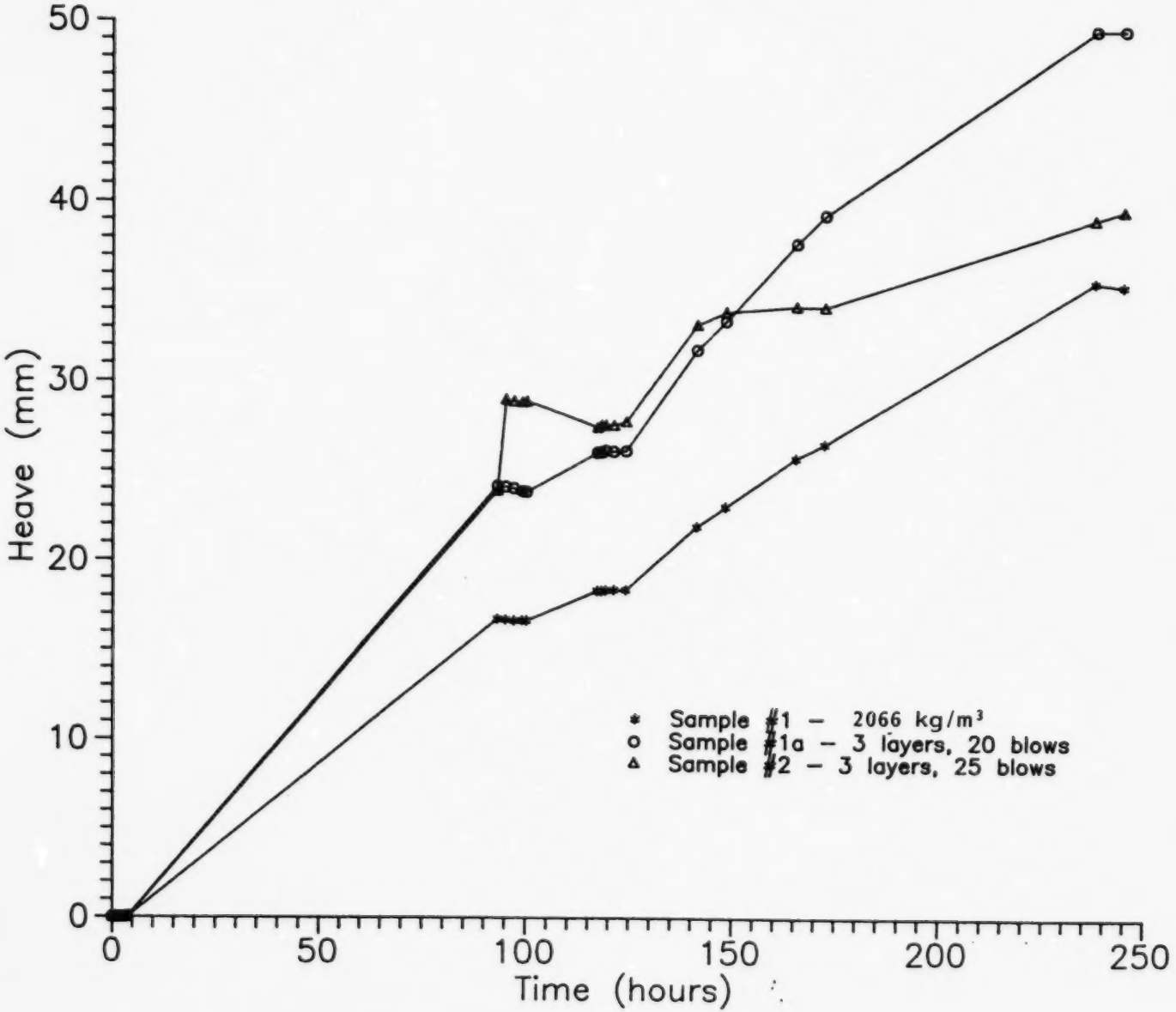


FIGURE 9
FROST BOX TEST RESULTS - OTTAWA HAWTHORNE TS

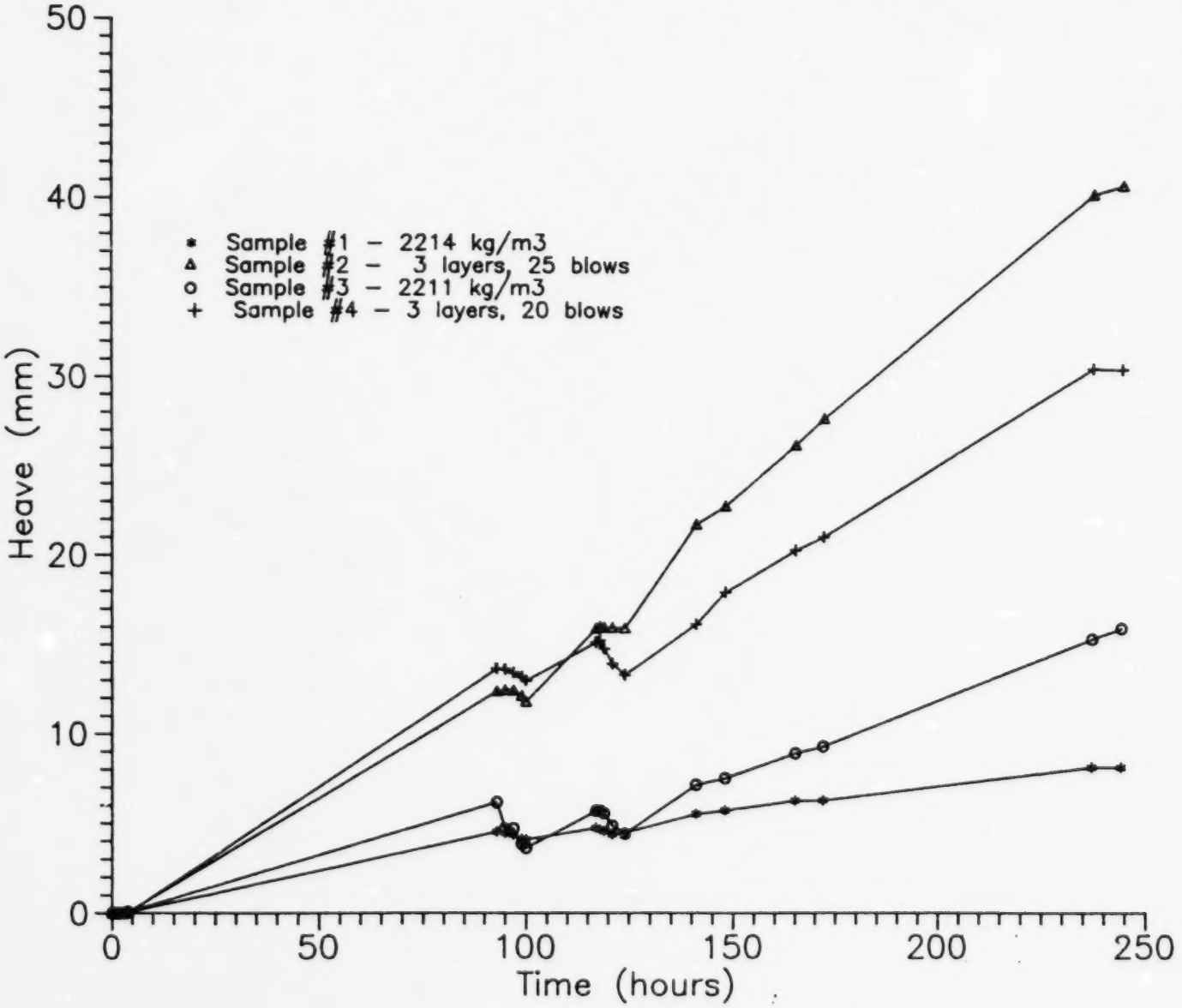


FIGURE 10
FROST BOX TEST RESULTS - PINARD TS

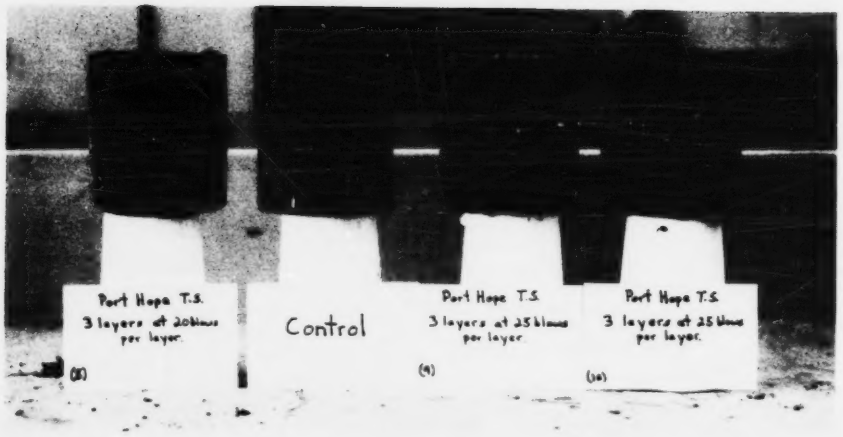


FIGURE 11
PORT HOPE TS SPECIMENS SHOWN AFTER TESTING

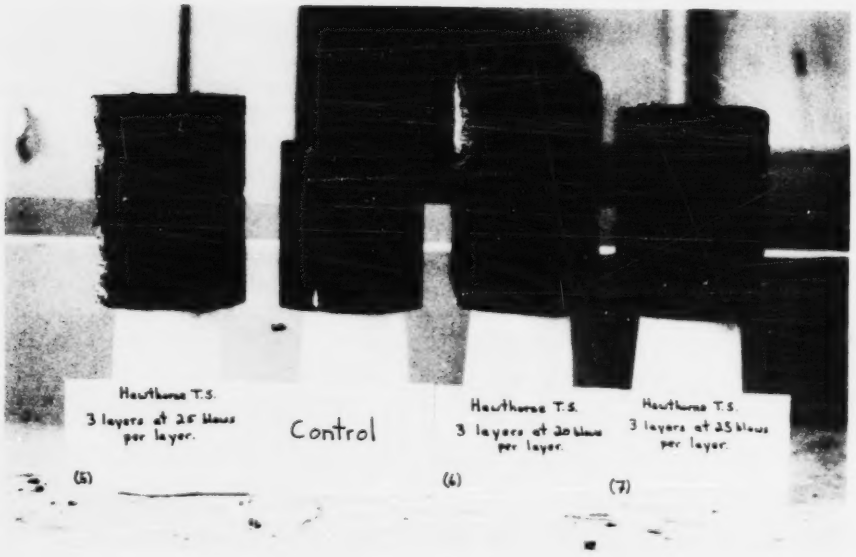


FIGURE 12
OTTAWA HAWTHORNE SPECIMENS SHOWN AFTER TESTING

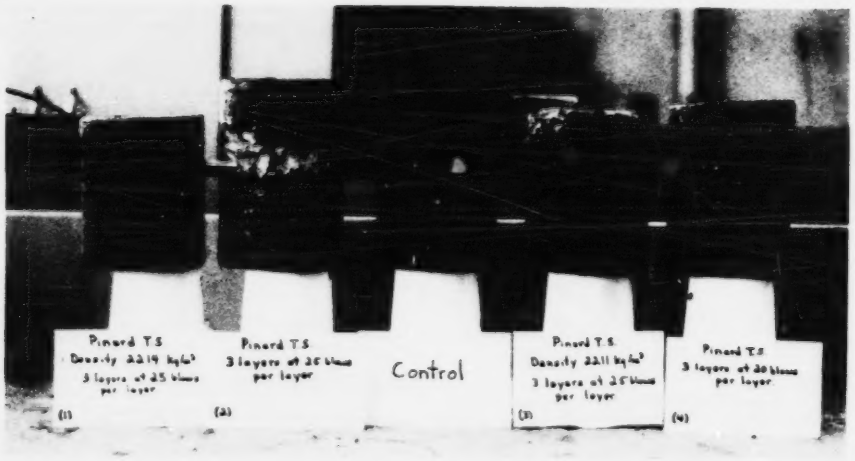


FIGURE 13
PINARD TS SPECIMENS SHOWN AFTER TESTING

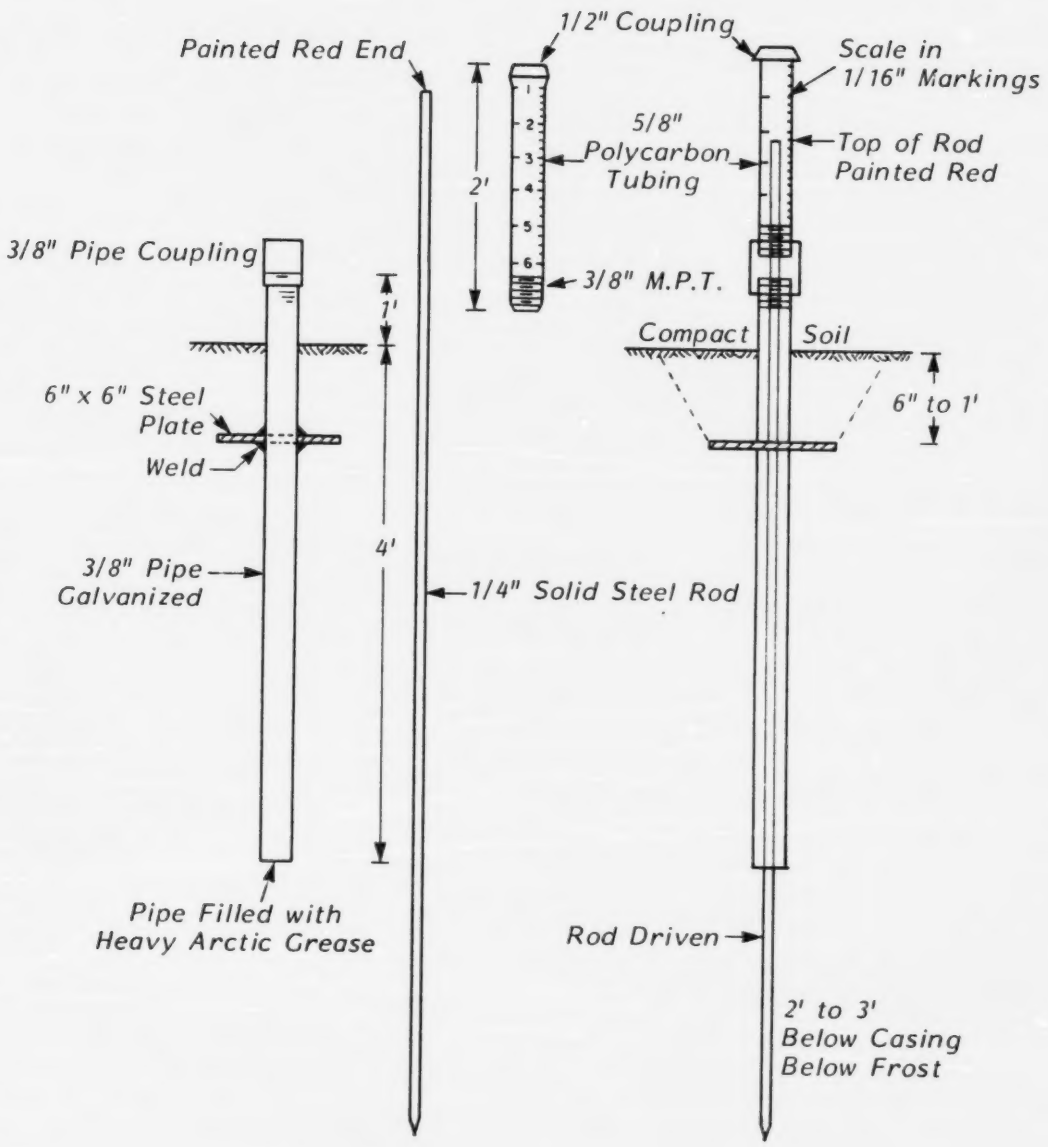


FIGURE 14
FROST HEAVE GAUGE

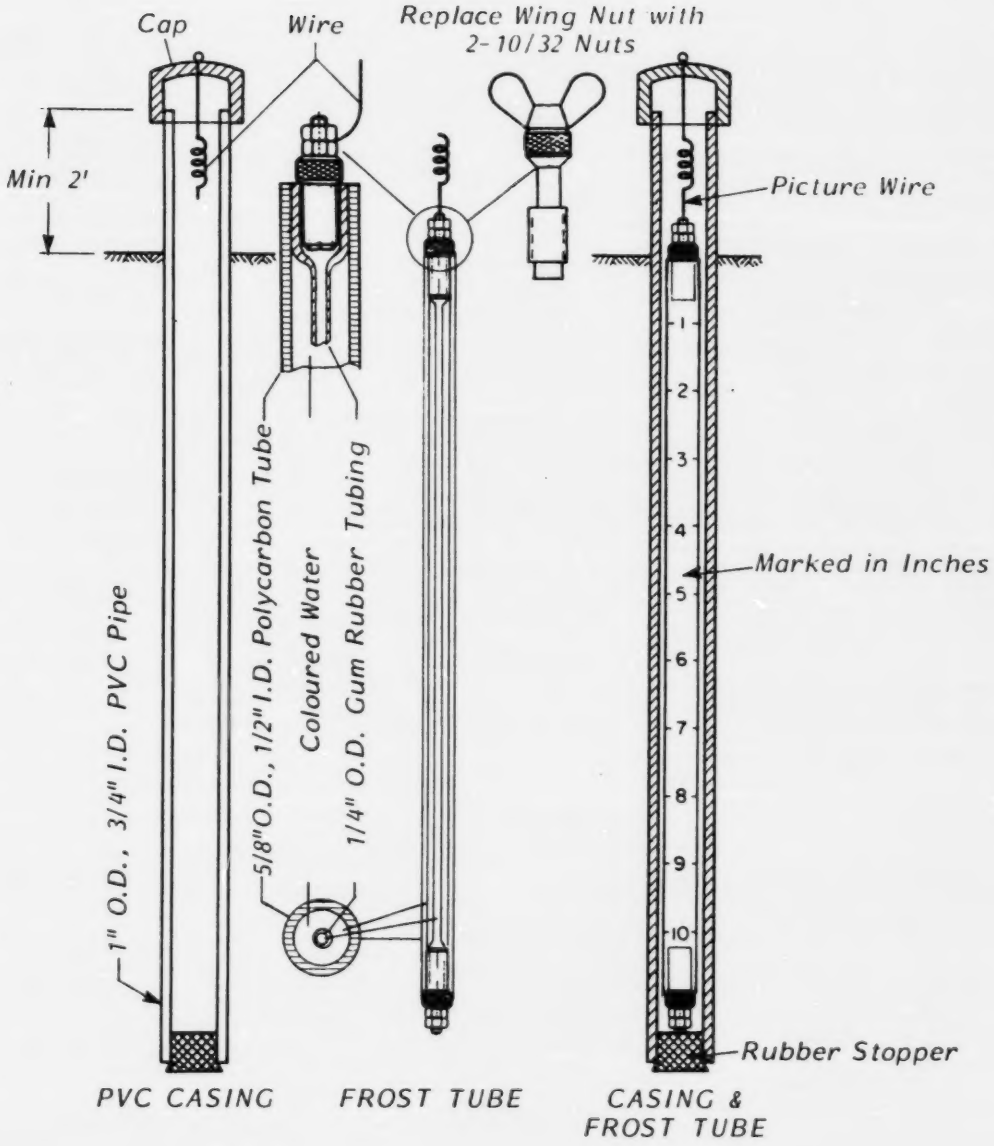


FIGURE 15
FROST DEPTH CAUGE

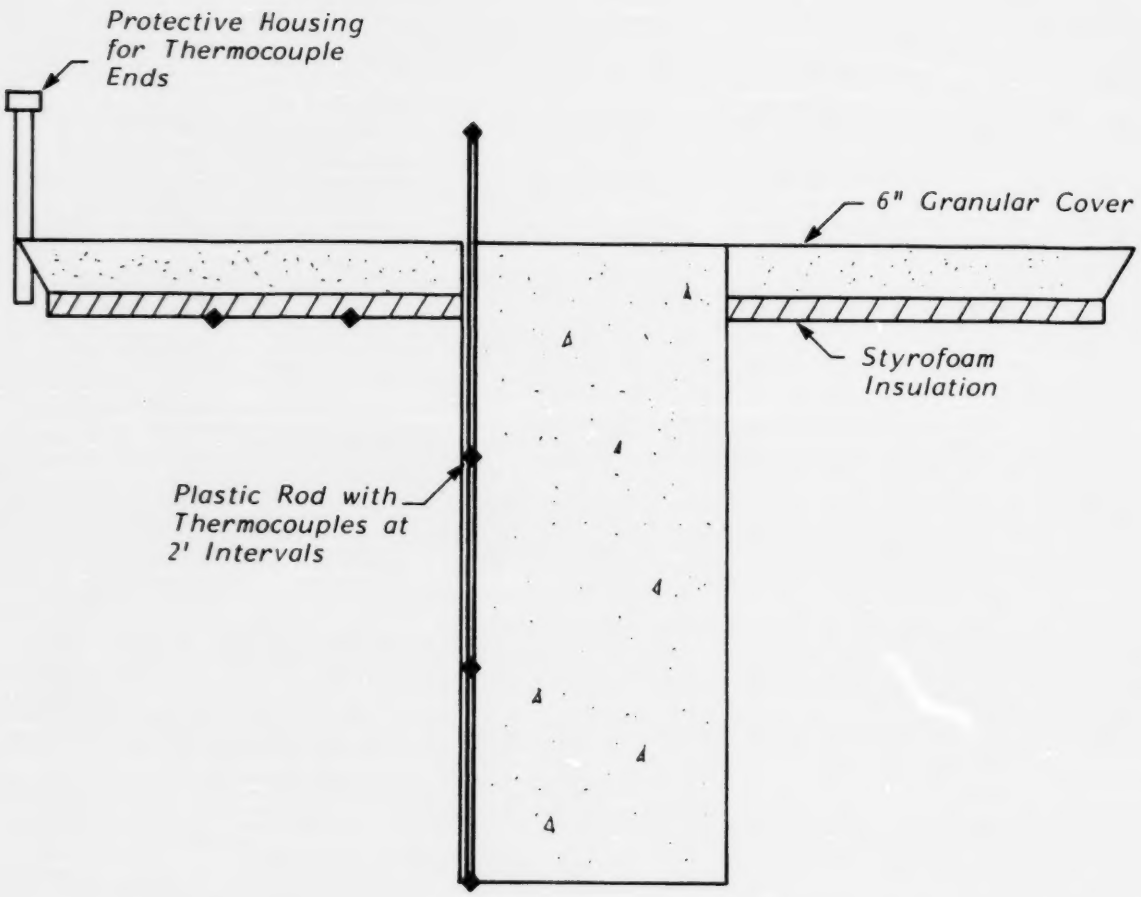
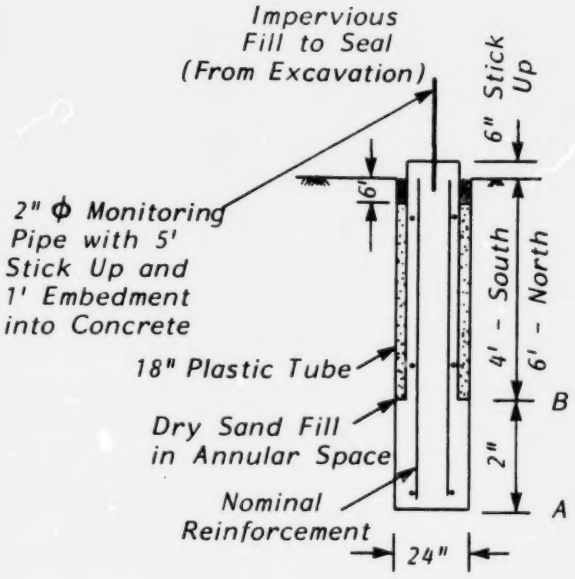
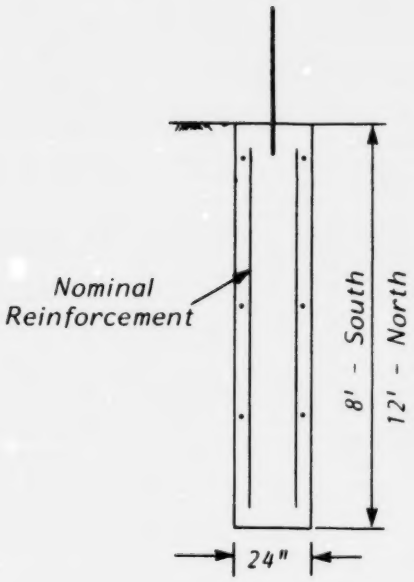


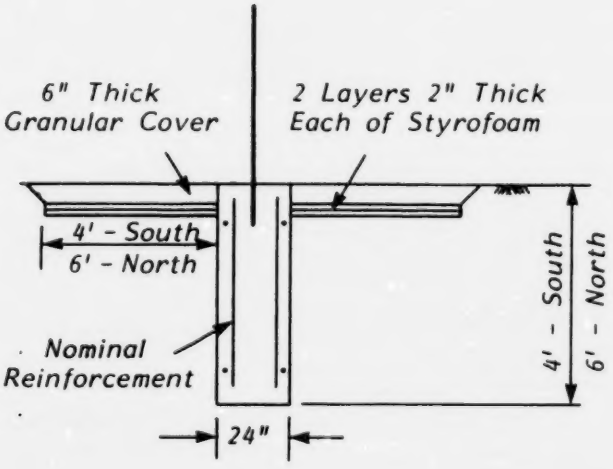
FIGURE 16
INSULATED FOOTING WITH THERMOCOUPLE TREE (◆)



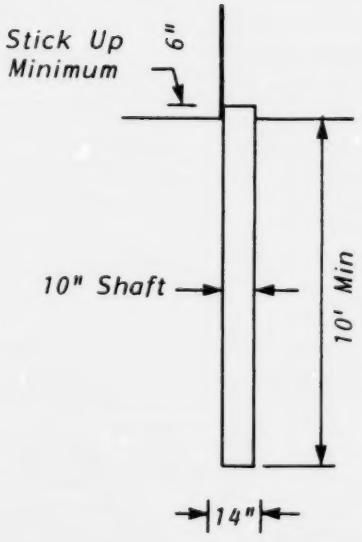
SHAFT/SLEEVE FOOTING



AUGERED FOOTING



INSULATED FOOTING

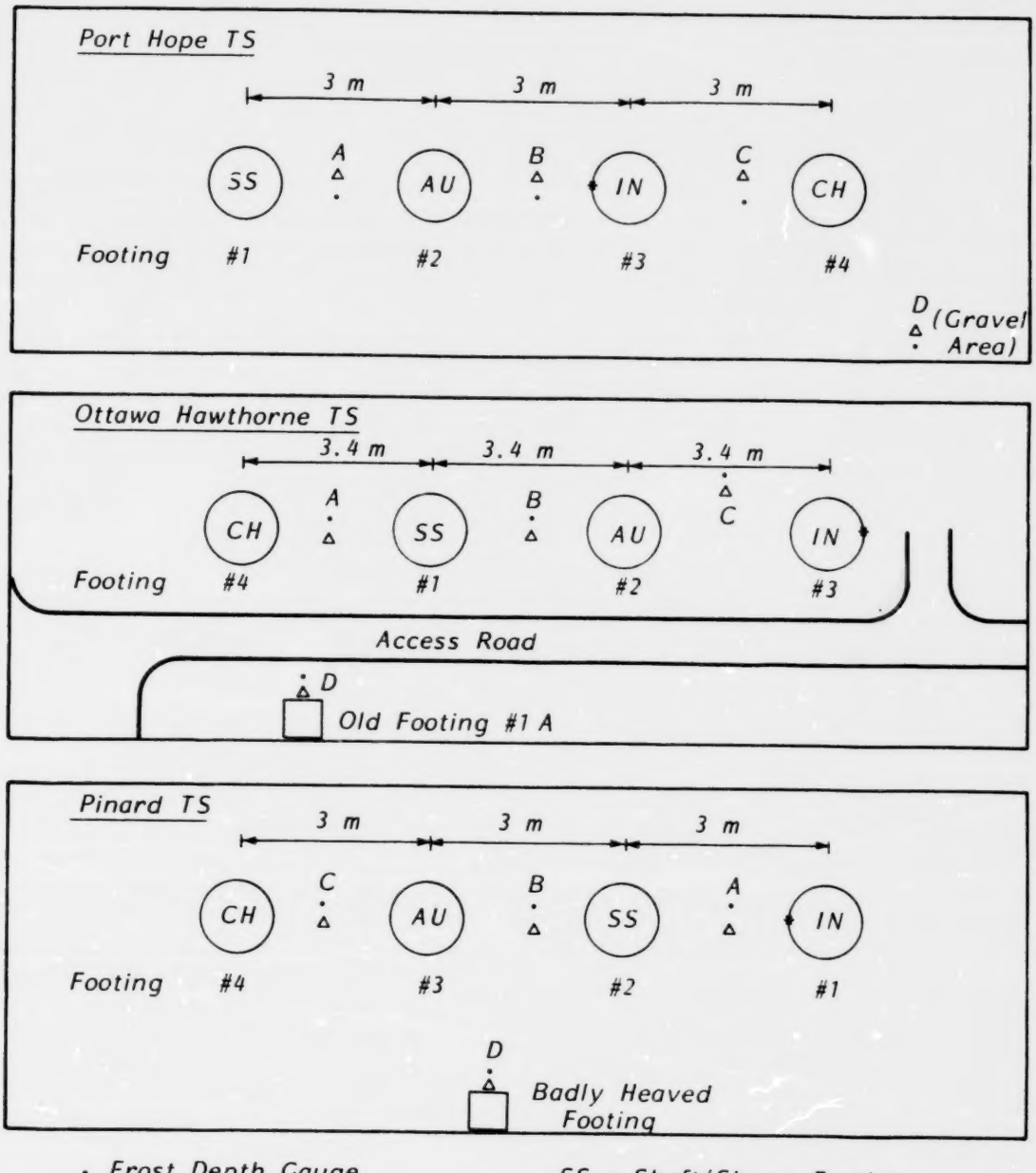


CHANCE STREET LIGHT FOOTING

FIGURE 17

FOUR TEST FOOTINGS INSTALLED AT PORT HOPE TS,
OTTAWA HAWTHORNE TS AND PINARD TS

175707-RD



• Frost Depth Gauge

△ Frost Heave Gauge

* Thermocouple Tree

SS = Shaft/Sleeve Footing

AU = Augered Footing

IN = Insulated Footing

CH = Chance Screw-in Footing

FIGURE 18

FROST INSTRUMENTATION AND TEST FOOTINGS LAYOUT AT THREE TEST SITES

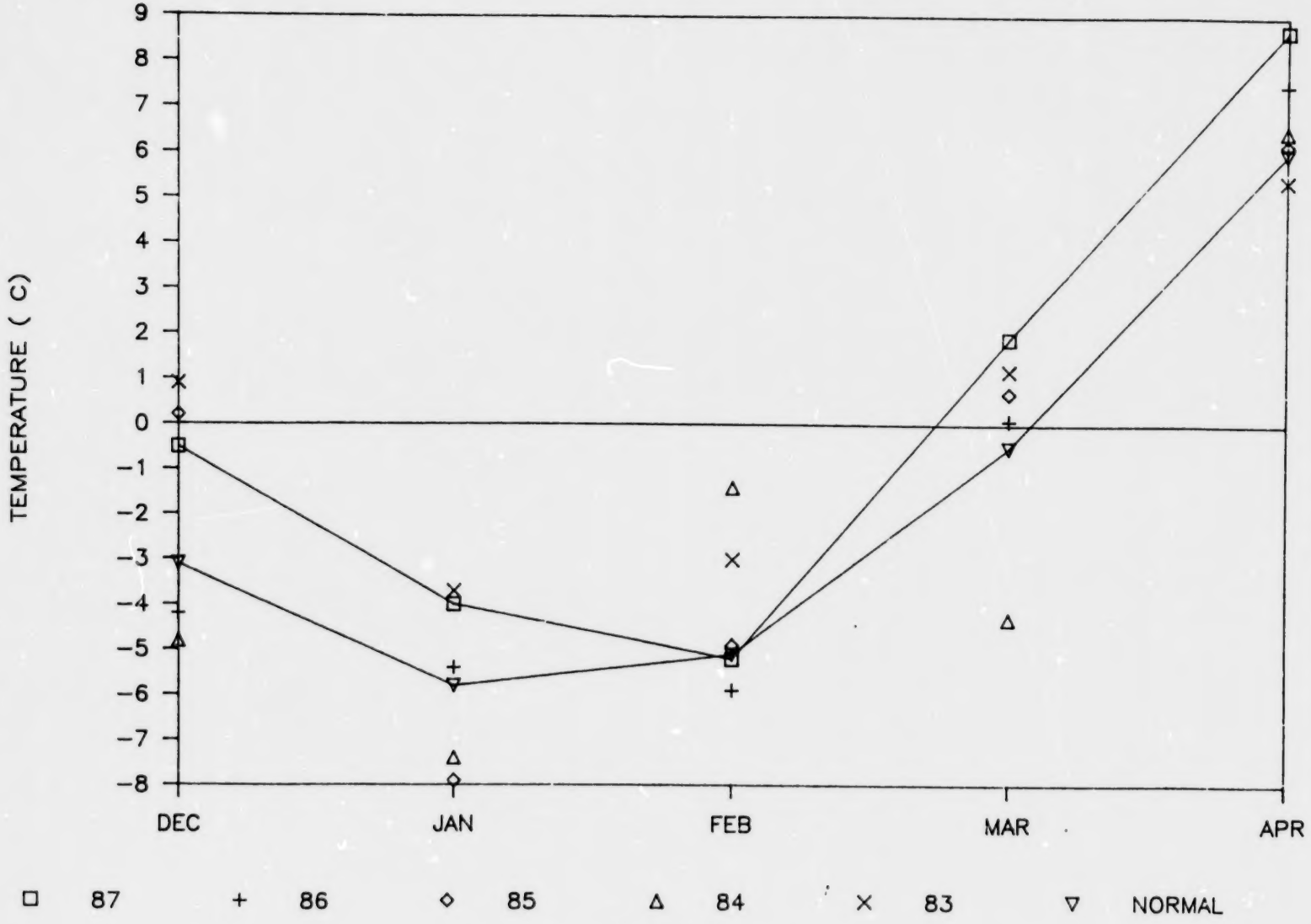


FIGURE 19
MONTHLY MEAN TEMPERATURES - PORT HOPE

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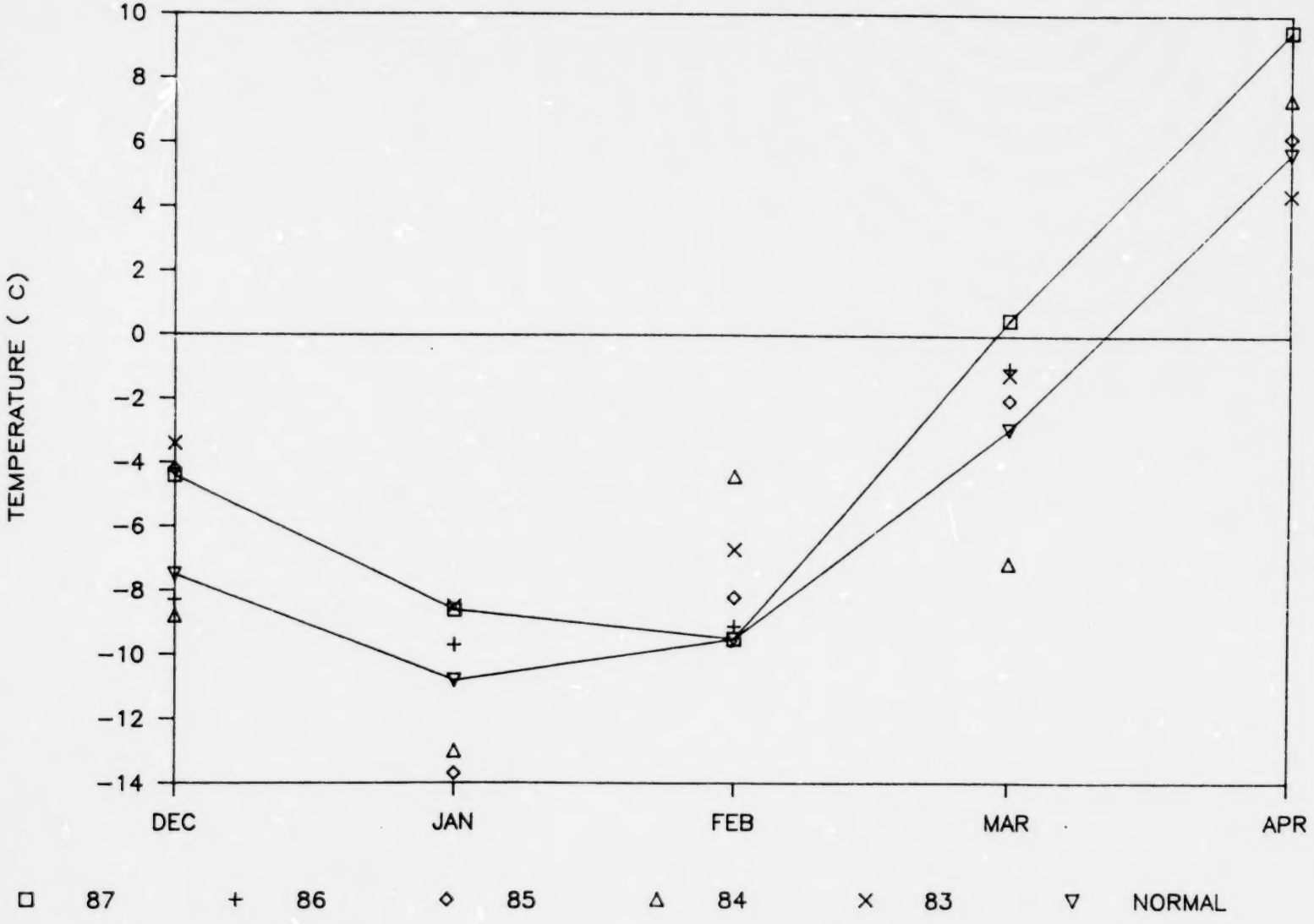

FIGURE 20
MEAN MONTHLY TEMPERATURES - OTTAWA CDA

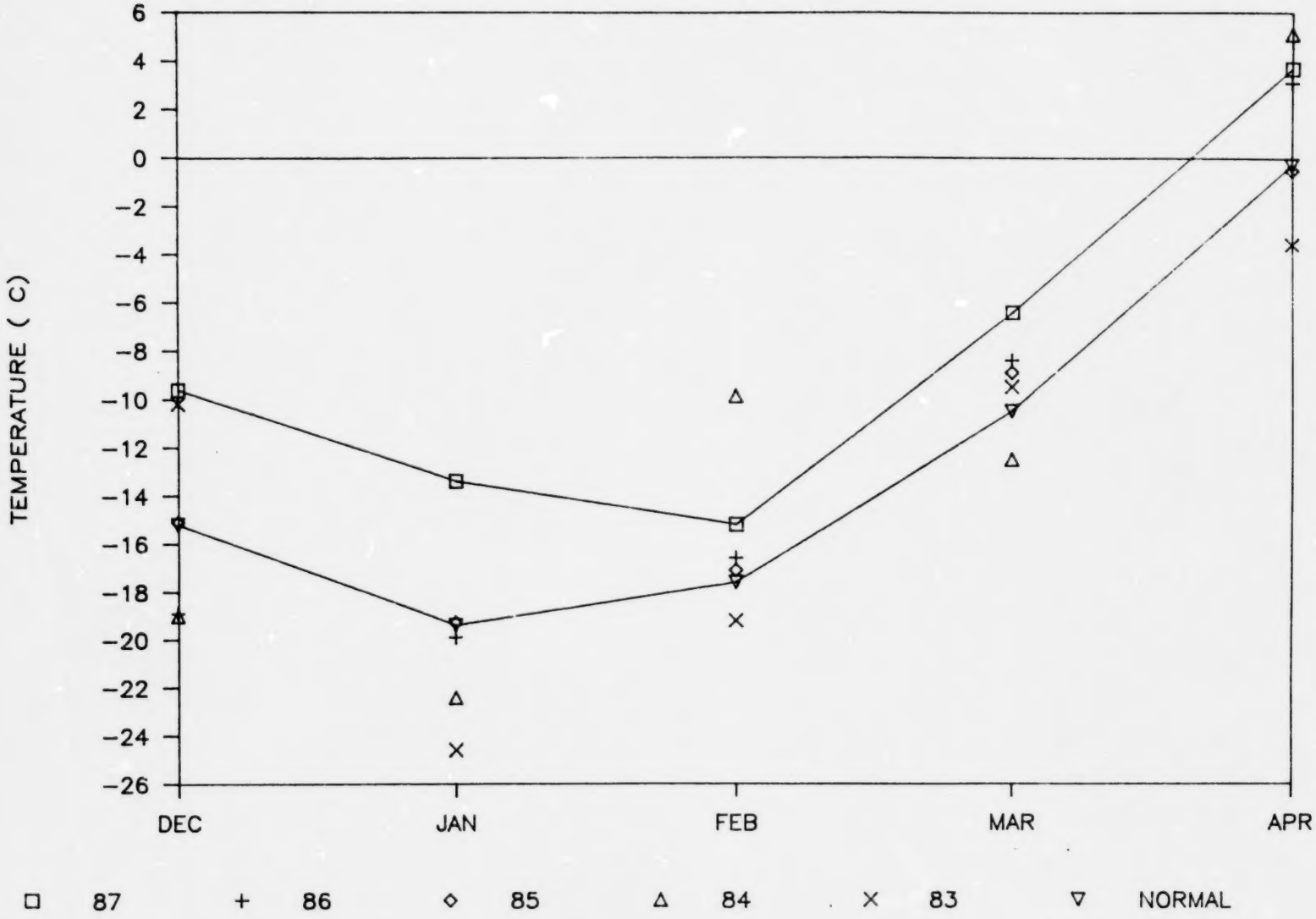

FIGURE 21
MONTHLY MEAN TEMPERATURES - ISLAND FALLS

175722-RD
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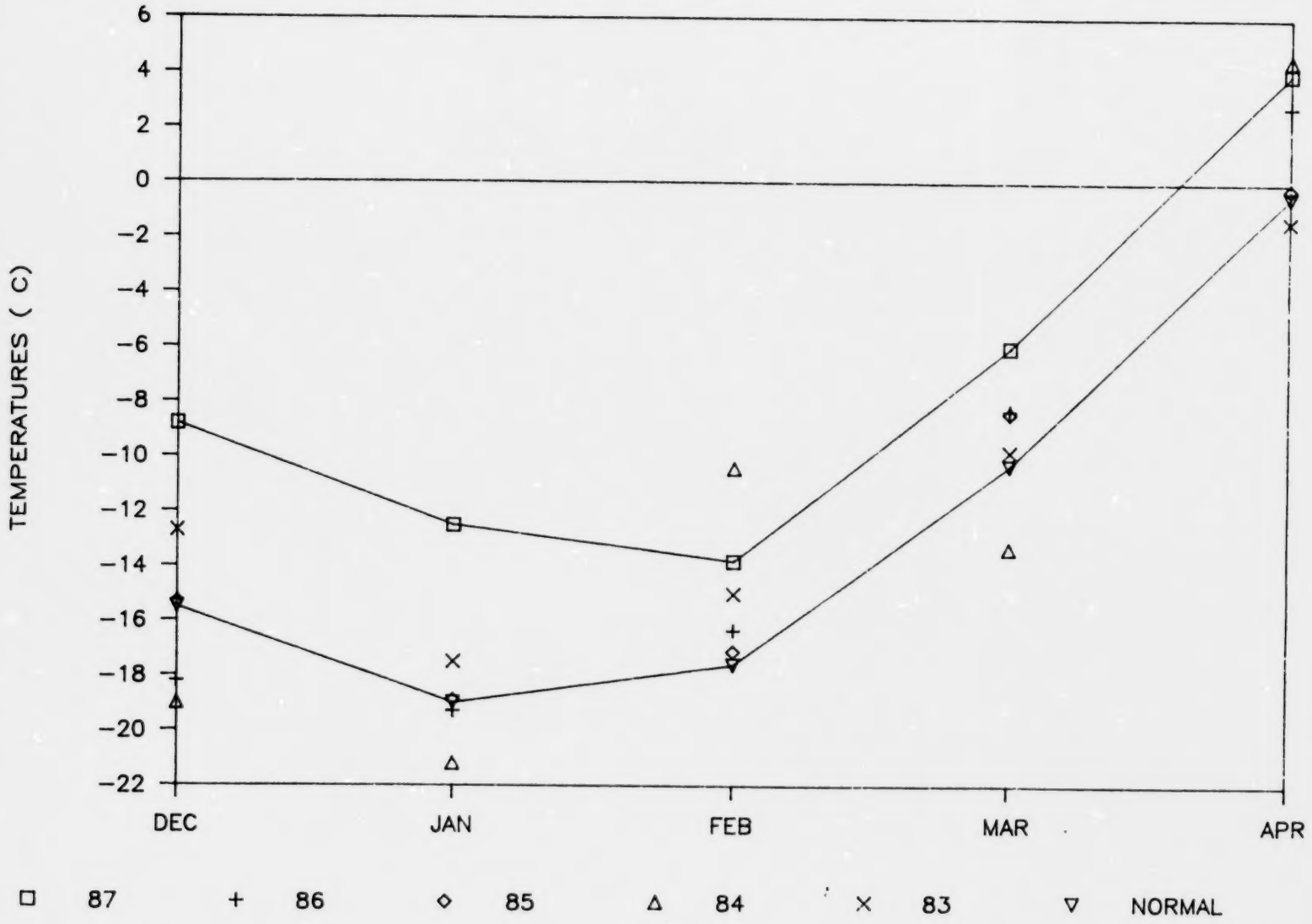

FIGURE 22
MONTHLY MEAN TEMPERATURES - SMOKY FALLS

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